DESCRIPTION

ECB-TYPE COLOUR LIQUID CRYSTAL DISPLAY WITH RESTRAINED TEMPERATURE
DEPENDENCY OF COLOUR TONE

TECHNICAL FIELD

This invention relates to a liquid crystal

5   display device, and more particularly relates to a

liquid crystal display device of an ECB type

(electrically controlled birefringence effect type).

BACKGROUND ART

10   Nawadays, liquid crystal display devices are in

widespread use in various monitors for personal

computers or the like, display devices for cellular

phones, and so forth, and are expected to increasingly

spread hereafter, and in fact, it is being planned to

15   develop their use in large-screen television sets. In

such liquid crystal display devices, what is called a

micro color filter system is widely used as a color

display system.

With this system, one pixel is divided into at

20   least three subpixels, for each of which red, green

and blue color filters are formed to perform

full-color display. This system has such an advantage

that high color reproduction performance can be

materialized with ease. However, in this system, there

25   is a disadvantage such that transmittance comes to be

1/3 so that light utilization efficiency is lowered.

In such a low light utilization efficiency, a

problem is raised in that it is necessary to increase

the luminance of a back light or a front light in an

attempt to achieve bright display so that visibility

can be improved, resulting in a high power consumption,

5   in the case of a transmission type liquid crystal

display device or semi-transmission type liquid

·crystal display device having a back light, or a

reflection type liquid crystal display device having a

front light.

10   That low light utilization efficiency results in

a more serious problem in the case of a reflection

type liquid crystal display device making use of no

front light. That is, a reflection type liquid crystal

display device having RGB color filters can secure

15   sufficient visibility in the very bright outdoors, but

it is difficult to secure sufficient visibility in

dark places and even in an environment of offices or

homes.

Meanwhile, as a color liquid crystal display

20   device which performs display without use of any color

filters, the liquid crystal display device of an ECB

type (electrically controlled birefringence effect

type) is conventionally known in the art.

This ECB type liquid crystal display device

25   includes a transmission type in which a liquid crystal

cell holding a liquid crystal is interposed between a

pair of substrates and a polarizing plate is disposed

on its front side and back side each, and a reflection
type including a single polarizing plate type in which
the polarizing plate is disposed only on one substrate,
and a double polarizing plate type in which the

5 polarizing plate is disposed on both the substrates
and a reflecting plate is provided on the outside of
one polarizing plate.

Here, in the case of, e.g., the transmission type
ECB type liquid crystal display device, the linear

10 polarization transmitted through one polarizing plate
to have entered becomes light each wavelength light of
which has turned to elliptical polarization in a
different polarization state by the birefringent
action of a liquid crystal layer while transmitted

15 through the liquid crystal cell. This light enters the
other polarizing plate, and the light transmitted
through the other polarizing plate becomes colored
light in a color corresponding to the ratio of light
intensity of each wavelength light which constitutes

20 that light.

That is, the ECB type liquid crystal display
device colors light by utilizing the birefringent
action of a liquid crystal layer of the liquid crystal
cell and the polarization action of at least one

25 polarizing plate. Since it is free of absorption of
light that takes place when color filters are used, it
can perform bright color display at high light

transmittace.

Moreover, the ECB type liquid crystal display device varies in birefringence of the liquid crystal layer depending on the state of alignment of liquid crystal molecules in accordance with the voltage applied across the electrodes of both the substrates of the liquid crystal cell. Following such variations, the polarization state is varied with each wavelength light entering the other polarizing plate, so that the color of colored light can be changed by controlling the voltage applied to the liquid crystal cell. Thus, a plurality of colors can be displayed in the same pixel.

Fig. 10 is a view showing retardation levels and colors corresponding thereto where the ECB type liquid crystal display device is driven under crossed Nicol (cross polarization). As shown in Fig. 10, colors change in accordance with birefringence levels. Here, when using as a liquid crystal mode, e.g., a material having negative Δε which stands perpendicularly aligned when no voltage is applied is used, black is displayed when no voltage is applied, and colors are so change as to be black → gray → white → yellow → red → purple → blue → yellow → purple → light blue → green with an increase in voltage.

However, the ECB type liquid crystal display device can display any desired colors in the same

pixel, but has such a problem that because of its mode
that utilizes the coloring relying on retardation,
display colors may be varied with changes in
retardation.

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DISCLOSURE OF THE INVENTION

The present invention is a liquid crystal display
device which comprises at least one polarizing plate,
a pair of substrates at least one of which is

10 transparent, and a liquid crystal layer of nematic
liquid crystal having negative dielectric constant
anisotropy which is filled between the substrates and
is aligned to be substantially perpendicular to the
substrates when no voltage is applied; and performs

15 monochrome and color displays by changing a
retardation level R of the liquid crystal layer by
controlling a tilt angle of molecular alignment of the
liquid crystals by applying a voltage; the device
being characterized in that in the liquid crystal

20 layer, a voltage range is present in which the rate of
change in the retardation level R with respect to
temperature T, $\Delta R/\Delta T$, becomes substantially zero under
conditions of application of a voltage not lower than
the threshold value of the Freedericksz transition and

25 the color displayed when voltage is applied at a
maximum voltage value in the voltage range is red or
purple.

The present invention is also characterized in that the color displayed when voltage is applied at a maximum voltage value in the voltage range is present in a display region corresponding to red or purple in

5   the xy chromaticity coordinates.

The present invention is still also characterized in that the color displayed when voltage is applied at a maximum voltage value in the voltage range is present in the region that satisfies two expressions,

10    $x > 0.4$ and $y < 0.45$, in the xy chromaticity coordinates.

The present invention is further characterized by having a liquid crystal element which is provided with the substrates and the liquid crystal layer and has a

15   large number of pixels, and in which a green color filter is used at a portion of each subpixel constituting the pixels.

The present invention is still further characterized in that the display is black display

20   when no voltage is applied.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing the structure of a liquid crystal display device according to an

25   embodiment of the present invention.

Fig. 2 is a graph showing a color difference threshold Wright and Pitt have found.

Figs. 3A and 3B are graphs showing the results of measurement of the temperature dependence of retardation where a liquid crystal element of the liquid crystal display device has a cell thickness of
5   3.7 microns and 4.5 microns.

Figs. 4A and 4B are graphs showing the results of measurement of the temperature dependence of retardation where the cell thickness of a liquid crystal element of the liquid crystal display device
10   is 5.8 microns and 9.0 microns.

Fig. 5 is a graph showing the results of measurement of the temperature dependence of color tones where the cell thickness of a liquid crystal element of the liquid crystal display device is 3.7
15   microns.

Fig. 6 is a graph showing the results of measurement of the temperature dependence of color tones where the cell thickness of a liquid crystal element of the liquid crystal display device is 4.5
20   microns.

Fig. 7 is a graph showing the results of measurement of the temperature dependence of color tones where a liquid crystal element of the liquid crystal display device has a cell thickness of 5.8
25   microns.

Fig. 8 is a graph showing the results of measurement of the temperature dependence of color

tones where the cell thickness of a liquid crystal element of the liquid crystal display device is 9.0 microns.

Fig. 9 is a view showing the pixel structure of a
5 liquid crystal element of the liquid crystal display device.

Fig. 10 is a graph showing changes in color with changes in retardation level of a conventional liquid crystal display device.

10   Fig. 11 is a graph showing the results of measurement of the temperature dependence of retardation.

BEST MODES FOR PRACTICING THE INVENTION
15   Embodiments of the present invention are described below in detail.

Fig. 1 is a sectional view showing the structure of a liquid crystal display device according to an embodiment of the present invention. In Fig. 1,
20 reference numeral 70 denotes the liquid crystal display device; and 80, a liquid crystal element held between a pair of polarizing plates 87a and 87b whose polarizing axes cross each other at right angles. This liquid crystal element 80 is formed by filling nematic
25 liquid crystals (hereinafter simply "liquid crystal") 85 between a pair of substrates 81a and 81b formed of a highly transparent material such as glass or plastic.

Here, these substrates 81a and 81b are provided
with electrodes 82a and 82b formed of a material such
as ITO (indium-tin oxide) which are each to apply a
voltage to liquid crystals (layer) 85.

5   In addition, the electrodes may have an active
matrix structure constituted of dot-like transparent
electrodes disposed in matrix form on one substrate,
switching elements such as TFTs (thin-film
transistors), MIM (metal-insulator-metal) elements or

10   the like which are connected to the respective
transparent electrodes, and counter electrodes
provided in a given pattern on one side of the other
substrate.

On these electrodes 82a and 82b, respectively,

15   insulating films 83a and 83b may be optionally
provided which have the function of, e.g., preventing
these electrodes from being short-circuited. On the
insulating films 83a and 83b, alignment control films
84a and 84b are further provided which are kept in

20   contact with the liquid crystal 85 and function to
control the alignment state.

A liquid crystal display device 70 making use of
a usual ECB mode can perform RGB three-primary color
display by utilizing changes in retardation. Color

25   liquid crystal display devices utilizing it are known
in the art.

Here, as modes in which color display based on

such an ECB principle is possible, various alignment
modes such as a perpendicular alignment mode, a
parallel alignment mode, a HAN (hybrid aligned
nematic) mode and a bend (OCB) mode may be conceived

5   from the state of alignment of liquid crystal
molecules brought about when no voltage is applied.
Any of these are an alignment mode in which the
retardation level of the liquid crystal layer is
changed by application of voltage.

10   The present inventor has made extensive studies
on modes among these. As a result, it has come to
light that the perpendicular alignment mode is best in
order to minimize changes in display color due to
changes in temperature. The details thereof are

15   described below.

In the case of nematic liquid crystals, various
values of physical properties are changed with respect
to temperature. In particular, as a physical-property
parameter which influences display, the

20   refractive-index anisotropy (Δn) is known to have a
great temperature dependence. As examples in which
changes in characteristics due to temperature
dependence of such a physical-property value are
remarkably perceivable by human eyes, the following

25   two examples may be given.

1. A case in which a contrast ratio has
temperature dependence.

2. A case in which a color tone of display color
with high visual sensitivity (luminosity factor)
characteristics has temperature dependence.

In the perpendicular alignment mode, the present
5   invention minimizes the above two temperature
dependences simultaneously by employing the
constitution and drive conditions described below.

First, the temperature dependence of the contrast
ratio is primarily governed by temperature dependence
10   of black luminance. This black luminance can be made
free of temperature dependence by providing a
perpendicular alignment and normally black
constitution, i.e., by making black display when no
voltage is applied. More specifically, in the state
15   that liquid crystal molecules are upright when no
voltage is applied, no birefringence occurs.

That is, although the Δn, a physical-property
value of the liquid crystals, has the temperature
dependence, the liquid crystals are in the state of
20   perpendicular alignment, and hence its birefringence
level is always zero even when the temperature is
changed. By setting this state to be the black state,
it is possible to provide the constitution that the
black luminance is not change due to temperature.

25   On the other hand, the modes other than the
perpendicular alignment, such as the above parallel
alignment mode, HAN mode and bend (OCB) mode, the

retardation of the liquid crystal layer is present
when no voltage is applied, and hence it follows that
the temperature dependence of the Δn direcrly
influences optical characteristics.

5   Next, consideration is given to the minimization
of the temperature dependence of color tones.
Described here is the temperature dependence of
voltage-retardation characteristics of a liquid
crystal material having negative dielectric constant
10   anisotropy (Nn-type liquid crystal) which is used in
the perpendicular alignment mode.

With a gradual raise in an applied-voltage value
from a state that no voltage is applied, the
transformation of alignment begins to arise at a
15   voltage value not lower than the threshold value of
the Freedericksz transition. More specifically, liquid
crystal molecules come to deviate from
perpendicularity with respect to the substrates, and
this inclination (gradient) becomes larger with an
20   increase in voltage. With a further rise in the
voltage, almost all the molecules of the liquid
crystal layer shortly come to be aligned in the
direction parallel to the substrates, and no
deformation arises any longer. The voltage at this
25   point is called the saturated voltage.

As well known, this transformation is determined
by the voltage, and does not depend on the cell

thickness. The angle of inclination θm of liquid
crystal molecules at the cell middle portion (bulk)
may be found by calculation according to the elastic
continuum theory. In the calculation made here, it is
5   necessary to know values of physical properties such
as elasticity constant. From the values of alignment
state and refractive-index anisotropy thus found, the
birefringence level brought about when voltage is
applied is found by calculation.

10   The present inventor has measured the temperature
dependence of retardation values of the Nn-type liquid
crystal. As a result, they have discovered that there
are materials on which the temperature dependence of
retardation values is little seen at a voltage value
15   between the threshold value of the Freedericksz
transition and the saturated voltage.

Fig. 11 shows the results of actual measurement
thereon. With the value of effective refractive-index
anisotropy (Δn.eff) found by dividing the retardation
20   value by the cell thickness as ordinate and
temperature as abscissa, results according to various
applied voltages of from 1.5 V to 5 V were plotted.

The retardation values little change in the
temperature range of from 0°C to 60°C where the voltage
25   is in the range of from 2.9 V to about 3.2 V. When
viewed in the range of from 0°C to about 35°C, which is
an actual-service temperature range, the voltage range

in which the retardation can be deemed to be free of
the temperature dependence can be said to be from 0 V
to about 4 V.

Although these liquid crystal materials have

5   temperature dependence on the Δn of the liquid crystal
materials themselves, it is presumed that the
temperature dependence of the elasticity constant that
influences the alignment transformation has cancelled
the temperature dependence of the Δn, so that the

10   voltage range has been materialized in which the
temperature dependence of the retardation level is
very small or does not substantially exist.

On the other hand, with regard to the above
materials as well, it can be seen also from Fig. 11

15   that the retardation value in the voltage range close
to the value of saturated voltage shows a very large
temperature dependence. This is considered as follows:
Upon application of sufficiently high voltage, almost
all the liquid crystal layer extending from the bulk

20   to the interfaces has been aligned in the direction
parallel to the substrates, so that it is directly
influenced by the temperature dependence of the Δn,
and the temperature dependence of the retardation
level as a consequence become very large.

25   That is, the temperature dependence of the
retardation level is very small at an intermediate
voltage, and the temperature dependence of the

retardation is remarkable at high voltage.

Accordingly, the voltage range in which the temperature dependence of the retardation level is small can be preferably utilized in order to perform

5. color display having small temperature dependence.

In practice, however, the condition that the retardation little changes due to temperature is often limited to a narrow voltage range. In such a case, a voltage must be applied which can make the temperature

10 dependence small only in specific colors and is compatible with temperatures at the time of displaying other colors.

In such a case, red or purple may preferably be displayed at the maximum voltage among voltages where

15 changes are small so that the color tone of the red or purple is not changed by temperature.

The retardation value of blue or green may also be so set that it comes to this voltage range where the temperature dependence is small. However, the red

20 or purple has a smaller retardation value than the blue or green, and hence the retardation value of the red or purple may be set to the maximum value in this voltage range, whereby the cell thickness can be made smaller in the same voltage range. As a result, the

25 response speed can be increased.

If blue is displayed when the retardation value of the red or purple can be set to the maximum value

in this voltage range, the retardation value becomes
larger than that of the red or purple results and it
is necessary to apply a high voltage, where the
temperature dependence of color tone in the blue is

5   brought about, but can be made not so conspicuous in
the following way.

Fig. 2 presents a color difference threshold
Wright and Pitt have found (Noboru Ohta, "Shikisai
Kogaku (Color Optics)", p.116). According to this

10   article, colors of from green to red are perceivable
even when the wavelength deviates by 2 nm or less,
whereas blue is not perceivable until the wavelength
deviates by 4 nm or more. This is considered due to
the fact that human's visual sensitivity (luminosity

15   factor) to blue is not good.

That is, even when the color tone has no
temperature dependence in respect of red or purple and
has temperature dependence in respect of blue as in
the liquid crystal display device of the present

20   invention, the temperature dependence of the blue can
not easily be sensed for the above reason.

Employing the element constitution as described
above, it is possible to materialize a multi-color
display element which can display monochrome, and red,

25   purple and blue, and a liquid crystal display device
70 (liquid crystal element 80) on which no temperature
dependence of color display characteristics is visible.

In addition, in combination with subpixels having green color filters, i.e., using green color filters in some parts of subpixels constituting the pixels, a color display element capable of displaying colors

5 ranging over all the RGB can be produced.

In addition, for driving the liquid crystal element of the present invention, any systems of a direct drive system, a simple matrix system and an active matrix system may be used. The liquid crystal

10 display device 70 may also be of a transmission type, a reflection type, or a semi-transmission type. The substrate used may be a glass substrate or one which has a flexibility, such as a plastic substrate. When the reflection type is employed, various types of

15 reflecting sheets may be used as a reflecting sheet, such as what is called a front scattering sheet type in which a mirror reflecting sheet is used as the reflecting sheet and a scattering sheet is provided on the outside of the liquid crystal layer, and what is

20 called a directivity reflecting sheet, in which the shape of the reflecting sheet is devised to provide directivity.

Examples 1 to 3 of the present embodiment are given below.

25 As a common element structure used in Examples 1 to 3, the following was used.

As the structure of the liquid crystal layer, two

sheets of glass substrates having been subjected to perpendicular alignment were superposed one on another to form a cell, and a liquid crystal material MLC-6608 (available from Merck & Co., Inc.) having $\Delta\varepsilon < 0$ was capillary-injected thereinto as a liquid crystal material. Here, the cell thickness was changed so as to set retardation values in accordance with Examples.

As the structure of the substrate used, the following were used:

(1) a single-bit test cell for confirming retardation; and

(2) an active-matrix (AM) cell for confirming display characteristics.

Here, as to the single-bit test cell, two sheets of substrates on which a pattern comprised of squares of ITO wherein each side is 1 cm was formed were superposed one on another to form a test cell. As for the AM cell, an active-matrix substrate on which TFTs were disposed was used as one substrate, and a substrate on which color filters were disposed in accordance with Examples was used as the other substrate. In this case, the shape of pixels and the constitution of color filters were changed in accordance with Examples.

Aluminum electrodes were used as pixel electrodes on the TFT side to make up a reflection type, and a front scattering plate (manufactured by Polatechno Co.,

Ltd.) was provided on the outermost surface of the

substrate to enlarge the visual-field angle. Further,

in every cell, JALS2022-R1 (available from JSR

Corporation) was used as an aligning film in an

5   aligning film thickness of 100 nm, and this substrate

was rubbed to provide a pretilt angle. The pretilt

angle was set to about 3 degrees from the normal

direction of the substrate.

A broad-band λ/4 sheet (a phase compensation

10   sheet which can substantially satisfy the 1/4

wavelength condition in the visible region) was also

disposed between the above substrate (color filter

substrate) and the polarizing plate. Thus, a normally

black constitution was provided in which the liquid

15   crystal display device was in a dark state when no

voltage is applied and was in a light state when

voltage is applied.

To sum up the constitution used commonly, the

basic constitution was the same constitution as that

20   shown in Fig. 1, and the cell thickness and the color

filter constitution were changed in accordance with

Examples.

Example 1

Using the single-bit test cell, the temperature

25   dependence of retardation level was measured. The cell

thickness was set to be four kinds, 3.7 microns, 4.5

microns, 5.8 microns and 9.0 microns.

The results are shown in Fig. 3A as those on the cell thickness of 3.7 microns, in Fig. 3B as those on the cell thickness of 4.5 microns, in Fig. 4A as those on the cell thickness of 5.8 microns, and in Fig. 4B

5 as those on the cell thickness of 9.0 microns. As shown in these Figs. 3A to 4B, it was confirmed that the temperature dependence was not seen at 3 V in the cell having any cell thickness.

That is, it was confirmed in this Example that

10 in the liquid crystal material MLC-6608 having $\Delta\varepsilon < 0$, there is a voltage range in which the rate of change in the retardation level R with respect to temperature T, $\Delta R/\Delta T$, becomes substantially zero under the conditions that a voltage not lower than the threshold

15 value of the Freedericksz transition is applied, and that the maximum voltage value V1 in that voltage range was about 3 V.

Example 2

A substrate of 12 inches in diagonal and having a

20 number of pixels which correspond to SVGA (super video graphics array; 800 × 600 × 3) was used as the active-matrix substrate. Also, measurement was carried out at up to 5 V because of restrictions on its driver ICs and at 10°C to 30°C because of restrictions on

25 measurement environment. Using this cell, the temperature dependence of chromaticity was measured.

In addition, BM7 (manufactured by Topcon Corporation)

was used in the measurement. Here, the cell thickness
was set to be four kinds, 3.7 microns, 4.5 microns,
5.8 microns and 9.0 microns.

Results on the respective cell thicknesses are
5   shown in Figs. 5 to 8. As shown in Figs. 5 to 8, it
was confirmed that the temperature dependence was not
seen in the colors displayed under the drive
conditions of 3 V.

In Fig. 5, yellow was displayed even when 5 V was
10   applied, showing that the device had no sufficient
color display performance.

In Fig. 6, it was confirmed that display colors
of white $\rightarrow$ yellow $\rightarrow$ red $\rightarrow$ bluish purple were
obtained by increasing the voltage, and it was
15   confirmed by visual observation that color tones
changed depending on environmental temperature when
violet was displayed under application of 5 V.

In Fig. 7, it was confirmed that display colors
of white $\rightarrow$ yellow $\rightarrow$ red $\rightarrow$ purple $\rightarrow$ blue were
20   obtained by increasing the voltage.

That is, as in this Example, in the liquid
crystal layer, when applying 3 V of the maximum
voltage value in the voltage range in which the rate
of change in the retardation level R with respect to
25   temperature T, $\Delta R/\Delta T$, becomes substantially zero under
conditions of application of a voltage not lower than
the threshold value of the Freedericksz transition,

the color displayed is present in the region that
satisfies two expressions, $x > 0.4$ and $y < 0.45$, in
the xy chromaticity coordinates, i.e., the region in
which the color is red or purple.

5   Thus, inasmuch as the display color is present in
the red or purple region when voltage is applied at
the maximum voltage value, and where the cell
thickness is set to 5.8 microns, it is possible to
provide a liquid crystal element in which the

10   temperature dependence of color tones is not visible,
and a liquid crystal display device having such an
element.

In addition, as being seen in the drawing, the
results show that the temperature dependence was

15   present on the chromaticity coordinates when blue was
displayed under application of 4 V. However, any
changes corresponding thereto were not detected in
visual observation. Also, as to its response manner as
well, a good performance was shown, and animation

20   display, text scrolling and so forth were on the level
of no problem in practical use.

In Fig. 8, it was confirmed that display colors
of white → yellow → red → purple → blue were
obtained by increasing the voltage. Also, on the

25   chromaticity coordinates, blue was displayed under
application of 3 V and good results were obtained in
which no temperature dependence was seen in all the

display colors. However, in visual observation of its response manner, the response speed was found to be too low to adapt to animation display or text scrolling.

5   Thus, in this Example, it was confirmed that when the cell thickness is 5.8 microns, the temperature dependence of color tones is not visible and an appropriate response speed is obtainable.

Example 3

10   A cell was used in which the cell thickness of the active-matrix cell of Example 2 was set to 5.8 microns and a green color filter was provided in one subpixel of each pixel in the cell. Here, three subpixels constituting 800 × 600 pixels (SVGA) were

15   each constituted as shown in Fig. 9. That is, one subpixel was a subpixel with a green color filter, and the remaining two subpixels were so disposed as to be in an area ratio of 1:2.

As a result, it was ascertained that all the

20   primary colors RGB were able to be displayed. It was also ascertained that the color tones obtained did not change depending on temperature.

As described above, this Example showed that an ECB color liquid crystal element can be materialized

25   in which no temperature dependence of color tones is visible.

In the foregoing explanation, the reflection type

liquid crystal element has been described. However,
the present invnetion is not limited thereto, and as a
matter of course, applicable also to the transparent
type liquid crystal element and the semitransparent

5   type liquid crystal element. Also, in place of the
TFTs used as the driving means, MIM elements may be
used or a simple matrix structure may be employed.
Such a driving method may be used.

     As described above, as in the present invention,

10   in the nematic liquid crystal layer having negative
dielectric constant anisotropy in which a voltage
range is present in which the rate of change in the
retardation level R with respect to temperature T,
$\Delta R/\Delta T$, is substantially zero under conditions of

15   application of a voltage not lower than the threshold
value of the Freedericksz transition, the color
displayed when voltage is applied at a maximum voltage
value in the voltage range in which the rate of change,
$\Delta R/\Delta T$, is substantially zero, may be made to be red or

20   purple, thereby lessening to the utmost the change of
display color caused by change in temperature.